FORM PTO-1390 (REV. 9-2001) U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY 'S DOCKET NUMBER: 33420.00.0001

U S APPLICATION NO. (If known, see 37 CFR 1.5): 10/018755

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/EP00/04580	05/19/2000	06/18/1999

TITLE OF INVENTION
Device and Method for Predistorting a Transmittal Signal to be Transmitted Via a Nonlinear Transmission Path

APPLICANT(S) FOR DO/EO/US
Rainer PERTHOLD; Maximilian HOFMANN; Ingo ROGALSKY; Heinz GERHAEUSER

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☑ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. ☑ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☑ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ☐ is attached hereto (required only if not communicated by the International Bureau).
   b. ☑ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☑ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☑ is attached hereto.
   b. ☐ has been previously submitted under 35 U S.C. 154(d)(4).
7. ☐ Amendments to the claims of the International Aplication under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ An English lanugage translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 20 below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☑ A FIRST preliminary amendment.
14. ☐ A SECOND or SUBSEQUENT preliminary amendment.
15. ☐ A substitute specification.
16. ☐ A change of power of attorney and/or address letter.
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
18. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. ☑ Other items or information:
    Unsigned Declaration

U.S. APPLICATION NO (if known, see 37 CFR 1.5) 10/018755	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER

21. ☐ The following fees are submitted:	CALCULATIONS PTO USE ONLY	
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):		
Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1040.00**		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO **$890.00**		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO **$740.00**		
International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$710.00**		
International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 890.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	13 - 20 =	-0-	x **$18.00**	$	
Independent claims	4 - 3 =	1	x **$84.00**	$ 84.00	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ **$280.00**	$	
TOTAL OF ABOVE CALCULATIONS =				$	
☐ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2. +				$	
SUBTOTAL =				$ 974.00	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				$	
TOTAL NATIONAL FEE =				$	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$	
TOTAL FEES ENCLOSED =				$	
			Amount to be refunded:	$	
			charged:	$	

a. ☐ A check in the amount of $ _____ to cover the above fees is enclosed.

b. ☑ Please charge my Deposit Account No. 22-0259 in the amount of $ 974.00 to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☑ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 22-0259 . A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Christopher J. Reckamp, Esq.
Vedder Price Kaufman & Kammholz
222 N. LaSalle Street, Suite 2600
Chicago, IL 60601-1104

SIGNATURE

Christopher J. Reckamp

NAME

34,414

REGISTRATION NUMBER

IN THE UNITED STATES

☐☐ **RECEIVING OFFICE (RO/US)**
☒ **DESIGNATED OFFICE (DO/US)**
☐ **ELECTED OFFICE (EO/US)**

INTERNATIONAL APPLICATION NO	INTERNATIONAL FILING DATE	PRIORITY DATE ALLOWED
PCT/EP00/045809	20 MAY 2000	18 JUNE 1999

TITLE OF INVENTION DEVICE AND METHOD FOR PREDISTORTING A TRANSMISSION SIGNAL TO BE TRANSMITTED VIA A NONLINEAR TRANSMISSION PATH

APPLICANT(s)

Rainer PERTHOLD; Maximilian HOFMANN; Ingo ROGALSKY; Heinz GERHAEUSER

Box PCT
Commissioner of Patents and Trademarks
Washington DC 20231

VERIFIED CERTIFICATION OF EXPRESS MAILING DATE (INTERNATIONAL APPLICATION (37 CFR 1.10(C))

I declare that on December 17, 2001, I deposited with the United States Postal Service in an envelope "Express Mail, Post Office to Addressee", bearing Label Number EV 031724429 US, addressed to "Commissioner of Patents and Trademarks, Washington DC 20231" and having an express mail certification which I executed, the following papers:

Transmittal Letter (2 pages); Preliminary Amendment (16 pages); English Translation (25 pages); Five (5) sheets informal drawings;

A copy of these papers from the file of this application is attached.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application of any patent issuing thereon.

ROSALIE SWANSON

Typed or printed name of person making this verified statement

Date: December 17, 2001

Signature of person making this verified statement

CHICAGO/#862874.1

IN THE UNITED STATES

☐ RECEIVING OFFICE (RO/US)
☒ DESIGNATED OFFICE (DO/US)
☐ ELECTED OFFICE (EO/US)

INTERNATIONAL APPLICATION NO	INTERNATIONAL FILING DATE	PRIORITY DATE ALLOWED
PCT EP00/04580	20 MAY 2000	18 JUNE 1999

TITLE OF INVENTION. DEVICE AND METHOD FOR PREDISTORTING A TRANSMISSION SIGNAL TO BE TRANSMITTED VIA A NONLINEAR TRANSMISSION PATH

APPLICANT(s)

Rainer PERTHOLD; Maximilian HOFMANN; Ingo ROGALSKY; Heinz GERHAEUSER

Box PCT
Commissioner of Patents and Trademarks

Washington DC 20231

PRELIMINARY AMENDMENT

Prior to examination, please amend the above-identified application as follows:

In the Specification:

On page 1, after the title, please delete the heading "Description" and substitute therefor --Background of the Invention--, and the sub-heading --Field of the Invention--.

On page 2, at line 29, please insert the following heading: --Description of Prior Art--.

On page 9, at line 16, before the paragraph beginning "It is the object …", please insert the heading --Summary of the Invention--.

On page 9, please delete the paragraphs beginning at line 27 through page 10, line 12, and substitute therefor the following paragraph to read as follows:

According to a first aspect of the present invention this device for predistorting a transmission signal to be transmitted over a nonlinear transmission path which has an estimator for determining an error signal depending on the transmission signal and on a previously registered transfer characteristic of the nonlinear transmission path. The error signal represents an estimate of an error generated by the nonlinearity of the transmission path. A time-dispersive element is provided to generate a correction signal through temporal

extension of the error signal. The correction signal is combined with the transmission signal in a combiner. As a result of the temporal extension of the error signal an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the transmission signal.

On page 10, line 14, please insert the following new paragraphs:

According to a second aspect of the present invention this object is achieved by a high-frequency transmitter comprising:

a predistorter for predistorting a transmission signal to be transmitted over a nonlinear transmission path, said predistorter comprising:

an estimator for determining an error signal depending on the transmission signal and a previously registered transfer characteristic of the nonlinear transmission path, where the error signal represents an estimate of an error generated due to the nonlinearity of the transmission path;

a time-dispersive element for generating a correction signal by a temporal extension of the error signal; and

a combiner for combining the transmission signal and the correction signal,

wherein, due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the signal;

a power amplifier for amplifying a transmission signal which has been predistorted by the predistorter; and

a bandpass filter which succeeds the power amplifier and whose transmission band is adjusted to the useful frequency range of the transmission signal.

According to a third aspect of the present invention this object is achieved by a method for predistorting a transmission signal to be transmitted over a nonlinear transmission path, comprising the following steps:

generating an error signal from the transmission signal to be transmitted and a previously registered transfer characteristic of the nonlinear transmission path, wherein the error signal represents an estimate of an error generated due to the nonlinearity of the

transmission path;

effecting a temporal extension of the error signal to generate a correction signal;

combining the correction signal and the transmission signal to be transmitted to generate a predistorted transmission signal,

wherein, due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the transmission signal.

According to a fourth aspect this object is achieved by a method for spectrally forming an interference spectrum of a transmission signal at the output of a power transmitter, said method comprising the steps of:

generating an error signal from the transmission signal and a previously registered transfer characteristic of a power amplifier, wherein the error signal represents an estimate of an error generated due to a nonlinearity of the power amplifier;

effecting a temporal extension of the error signal to generate a correction signal;

combining the correction signal and the transmission signal to generate a predistorted transmission signal,

wherein , due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the power amplifier is shifted away from the useful frequency range of the transmission signal; and

feeding the predistorted transmission signal (S1') into the power amplifier.

On page 13, at line 24, before the paragraph beginning "Preferred Embodiments of the Present Invention ..., please insert the heading --Brief Description of the Drawings--.

On page 14, at line 9, after the description of Fig. 5 and 6, please insert the heading --Description of Preferred Embodiments of the Invention--.

In the Claims:

Please amend Claims 1-13 as follows:

1. (Once Amended) A device for predistorting a transmission signal to be transmitted over a nonlinear transmission path, comprising:

an estimator for determining an error signal depending on the transmission signal and a previously registered transfer characteristic of the nonlinear transmission path, where the error signal represents an estimate of an error generated due to the nonlinearity of the transmission path;

a time-dispersive element for generating a correction signal by a temporal extension of the error signal; and

a combiner for combining the transmission signal and the correction signal,

wherein, due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the signal.

2. (Once Amended) A device according to claim 1, wherein the nonlinear transmission path is a power amplifier.

3. (Once Amended) A device according to claim 1, wherein the estimator has a unit for forming the squares of the magnitudes of the transmission signal to be transmitted and a table for supplying complex distortion coefficients, which depend on the squares of the magnitudes and on the previously registered transfer characteristic of the nonlinear transmission path.

4. (Once Amended) A device according to claim 3, wherein the unit for forming the squares of the magnitudes of the real and the imaginary part of the transmission signal is provided.

5. (Once Amended) A device according to claim 1, wherein the estimator has an envelope detector for detecting the envelope of the transmission signal, a quantizer for forming quantized envelope values and a table unit for supplying complex distortion coefficients which depend on the quantized envelope values and on the previously registered transfer characteristic of the nonlinear trans-mission path.

6. (Once Amended) A device according to claim3wherein the estimator also includes a unit for combining the squares of the magnitudes or of the envelope values and the complex coefficients for generating the error signal.

7. (Once Amended) A device according to claim1, wherein the time-dispersive element is a time-dispersive bandpass filter or low-pass filter.

8. (Once Amended) A device according to claim 7, wherein an adapter is provided which, on the basis of a signal to be transmitted and an output signal output by a nonlinear transmission path if there is no predistortion, ascertains the transfer characteristic of the nonlinear transmission path and uses this to control the estimator and/or the filter coefficients of the time-dispersive bandpass filter or low-pass filter.

9. (Once Amended) A device according to claim 8, wherein the adapter ascertains the transfer characteristic at predetermined times.

10. (Once Amended) A high-frequency transmitter comprising:

a predistorter for predistorting a transmission signal to be transmitted over a nonlinear transmission path, said predistorter comprising:

an estimator for determining an error signal depending on the transmission signal and a previously registered transfer characteristic of the nonlinear transmission path, where the error signal represents an estimate of an error generated due to the nonlinearity of the transmission path;

a time-dispersive element for generating a correction signal by a temporal extension of the error signal; and

a combiner for combining the transmission signal and the correction signal,

wherein, due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the signal according to one of the claims 1 to 9;

a power amplifier for amplifying a transmission signal which has been predistorted by the predistorter; and

a bandpass filter which succeeds the power amplifier and whose transmission band is adjusted to the useful frequency range of the transmission signal.

11. (Once Amended) A method for predistorting a transmission signal to be transmitted over a nonlinear transmission path, comprising the following steps:

generating an error signal from the transmission signal to be transmitted and a previously registered transfer characteristic of the nonlinear transmission path, wherein the error signal represents an estimate of an error generated due to the nonlinearity of the transmission path;

effecting a temporal extension of the error signal to generate a correction signal;

combining the correction signal and the transmission signal to be transmitted to generate a predistorted transmission signal,

wherein, due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the trans-mission signal.

12. (Once Amended) A method for spectrally forming an interference spectrum of a transmission signal at the output of a power transmitter, said method comprising the steps of:

generating an error signal from the transmission signal and a previously registered transfer characteristic of a power amplifier, wherein the error signal represents an estimate of an error generated due to a nonlinearity of the power amplifier;

effecting a temporal extension of the error signal to generate a correction signal;

combining the correction signal and the transmission signal to generate a predistorted transmission signal,

wherein , due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the power amplifier is shifted away from the useful frequency range of the transmission signal; and

feeding the predistorted transmission signal (S1') into the power amplifier.

13. (Once Amended) A method according to claim 12, which also includes the step of performing bandpass filtering of an output signal [(S4)]output by the power amplifier.

In the Abstract:

Please amend the Abstract to read as follows:

A device for predistorting a transmission signal to be transmitted over a nonlinear transmission path comprises an estimator for determining an error signal depending on the transmission signal and a previously registered transfer characteristic of the nonlinear transmission path . The error signal represents an estimate of an error generated due to the nonlinearity of the trans-mission path. A time-dispersive element is provided to produce a correction signal by a temporal extension of the error signal. A combiner is provided to combine the transmission signal and the correction signal. As a result of the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the transmission signal.

REMARKS

Applicants respectfully submit that the claims are in condition for allowance. The Examiner is invited to contact the below-listed attorney if the Examiner believes that a telephone conference will advance the prosecution of this application.

December 17, 2001

Respectfully submitted,

Christopher J. Reckamp
Reg. No. 34,414

Vedder, Price, Kaufman & Kammholz
222 N. LaSalle Street, Suite 2600
Chicago, IL 60601-1104
(312) 609-7500
(312) 609-5005

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
AS DESIGNATED OFFICE (DO/US)

INTERNATIONAL APPLICATION NO	INTERNATIONAL FILING DATE	PRIORITY DATE ALLOWED
PCT/EP00/045809	20 MAY 2000	18 JUNE 1999

Applicant: Perthold et al.
U.S. Serial No. 10/018,755
Filing Date: December 17, 2001

Examiner:
Art Group:
Atty. Docket no. 34420.00.0001

Title: **DEVICE AND METHOD FOR PREDISTORTING A TRANSMISSION SIGNAL TO BE TRANSMITTED VIA A NONLINEAR TRANSMISSION PATH**

Box Non-fee Amendment
Assistant Commissioner for Patents
U.S. Patent and Trademark Office
Washington, D.C. 20231

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1/28/02 Rosalie Swanson
Date *Rosalie Swanson*

SECOND PRELIMINARY AMENDMENT

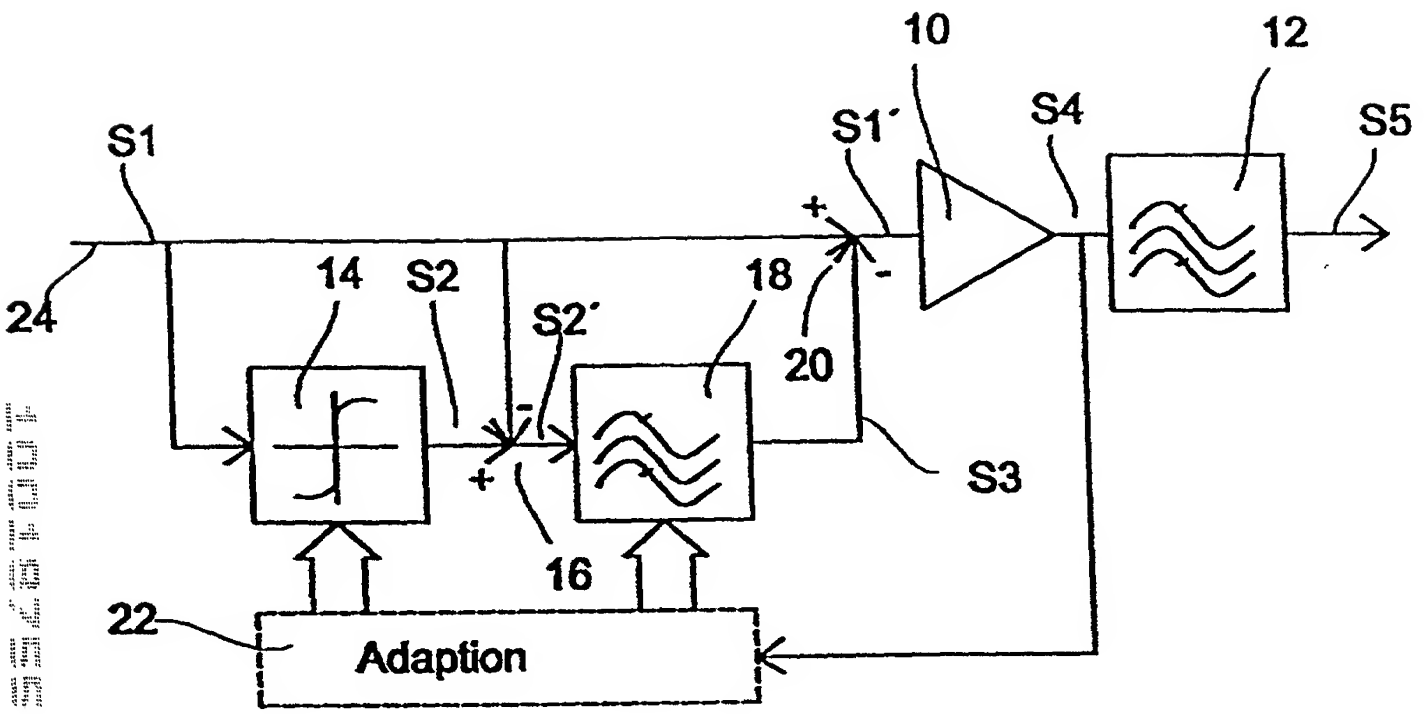
Applicants submitted an amended Fig. 1 in the case filed on December 17, 2001, which has been assigned SN 10/018,755 but did not submit a marked up version showing the change. Submitted herewith is a markup of the original FIG. 1 from the priority document to show by redline, the removal of a superfluous line to block 18 along with an amended Fig. 1 with the correction made. Applicants respectfully request acceptance of the drawing correction which amends FIG. 1 of the priority document as shown in red in the attached marked up drawing. The drawings are being submitted to the Official Draftsman under separate cover.

January 28 2002

Respectfully submitted,

Vedder, Price, Kaufman & Kammholz
222 N. LaSalle Street, Suite 2600
Chicago, IL 60601-1104
(312) 609-7599; FAX (312) 609-5005

Christopher J. Reckamp
Reg. No. 34,414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S1
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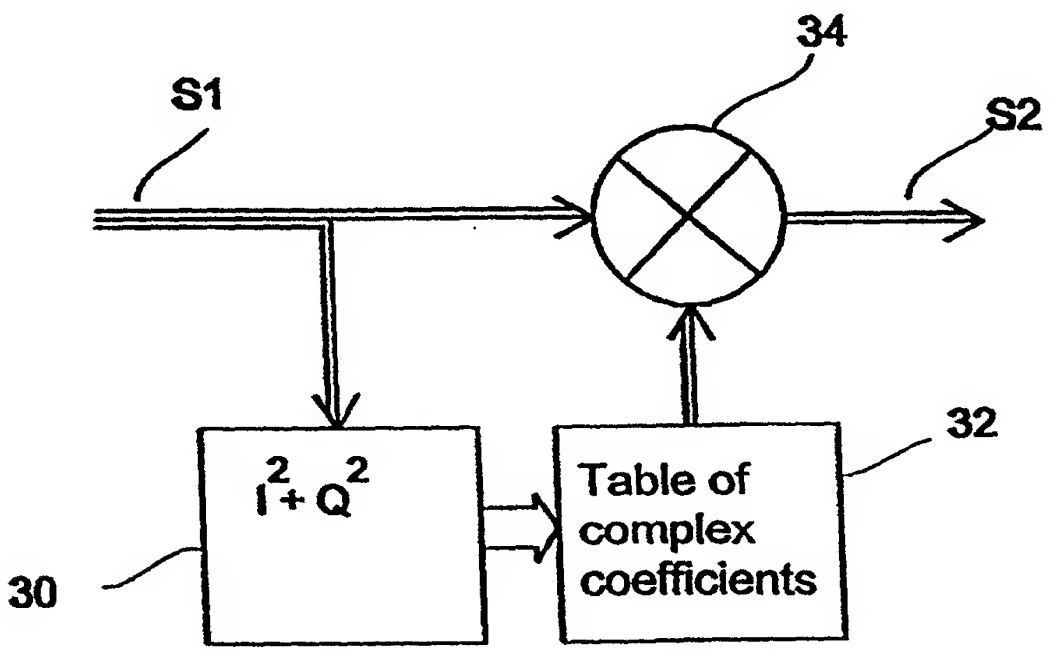
Adaption

Fig. 1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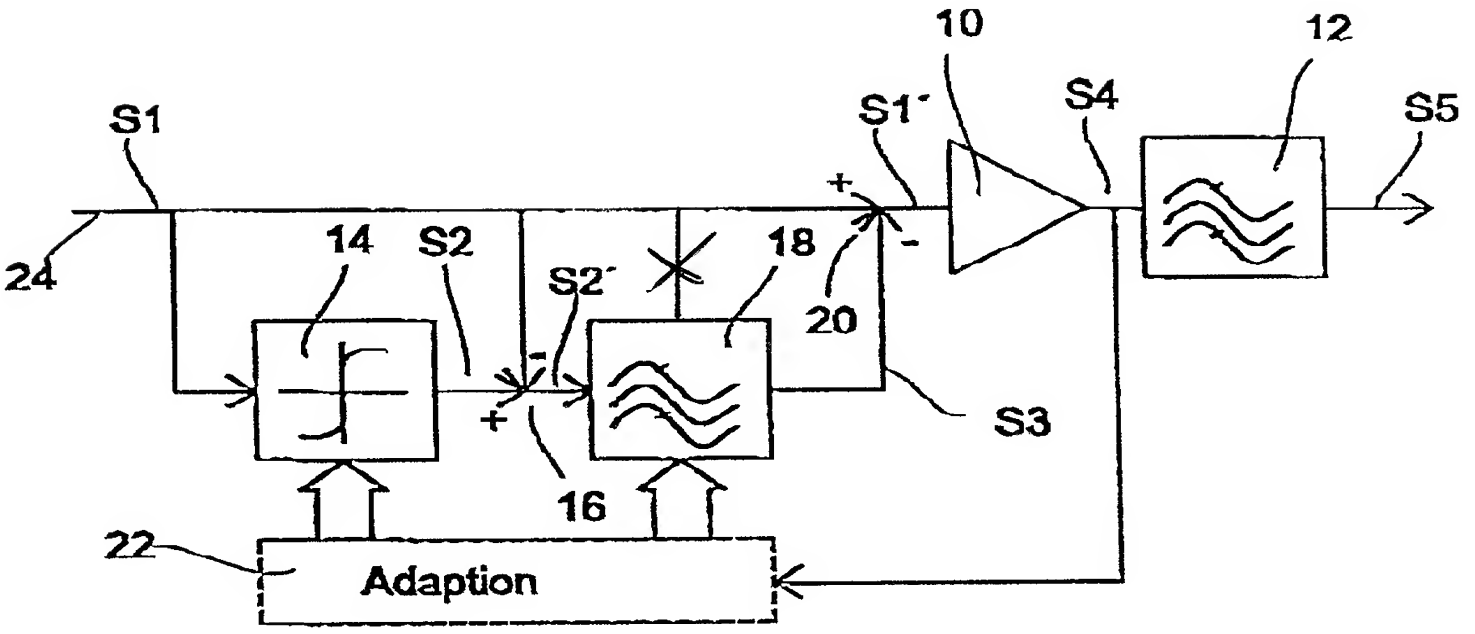
S1
S2
32
I^2+Q^2
Table of complex coefficients
30

Fig. 2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12
S1
S1'
S4
S5
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14
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S2'
18
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Adaption

Fig. 1

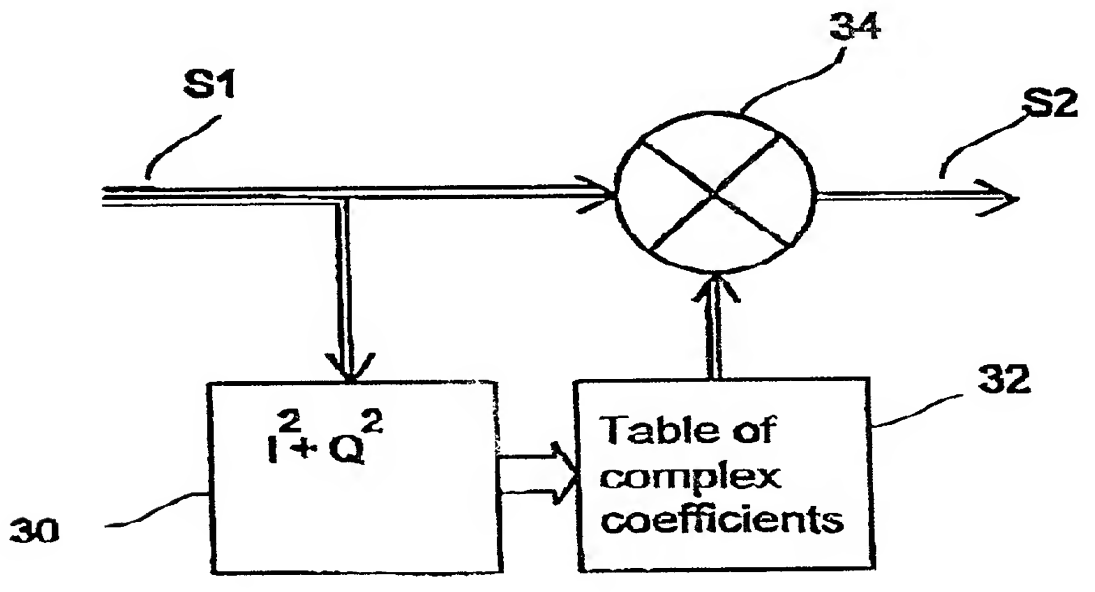
34
S1
S2
32
I^2+Q^2
Table of complex coefficients
30

Fig. 2

 #3

Atty. Docket 34420.00.0001

10/018755

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
AS DESIGNATED OFFICE (DO/US)

INTERNATIONAL APPLICATION NO	INTERNATIONAL FILING DATE	PRIORITY DATE ALLOWED
PCT/EP00/045809	20 MAY 2000	18 JUNE 1999

Applicant: Perthold et al.
U.S. Serial No. 10/018,755
Filing Date: December 17, 2001

Examiner:
Art Group:
Atty. Docket no. 34420.00.0001

Title: **DEVICE AND METHOD FOR PREDISTORTING A TRANSMISSION SIGNAL TO BE TRANSMITTED VIA A NONLINEAR TRANSMISSION PATH**

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Assistant Commissioner for Patents
U.S. Patent and Trademark Office
Washington, D.C. 20231

Attn: Official Draftsman

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1/28/02 Rosalie Swanson
Date *Rosalie Swanson*

LETTER TO THE OFFICIAL DRAFTSMAN

Submitted herewith is a markup of the original FIG. 1 from the priority document to show by redline, the removal of a superfluous line to block 18 along with an amended Fig. 1 with the correction made. Applicants respectfully request acceptance of the drawing correction which amends FIG. 1 of the priority document as shown in red in the attached marked up drawing.

January 28, 2002

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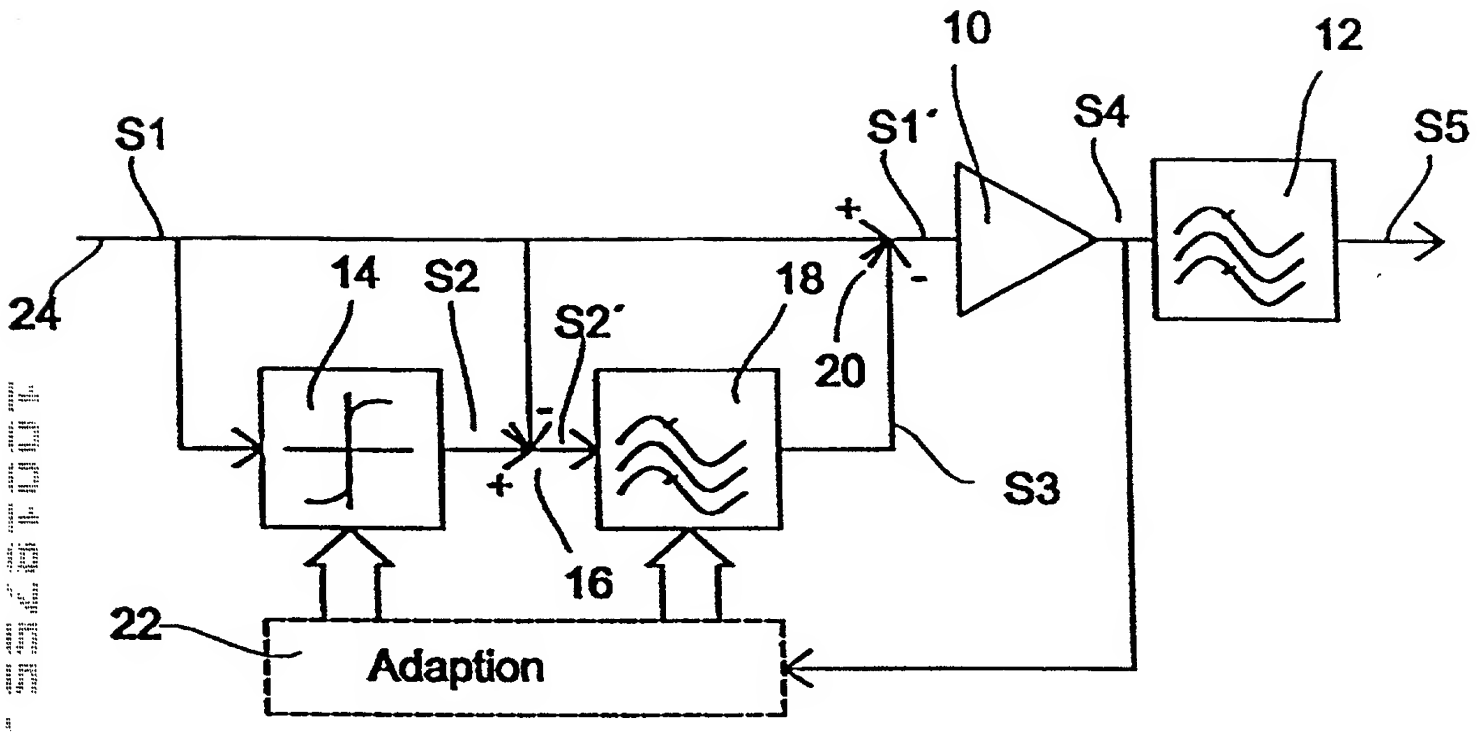
10
12
S1
S1'
S4
S5
+
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14
S2
S2'
18
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S3
16
22
Adaption

Fig. 1

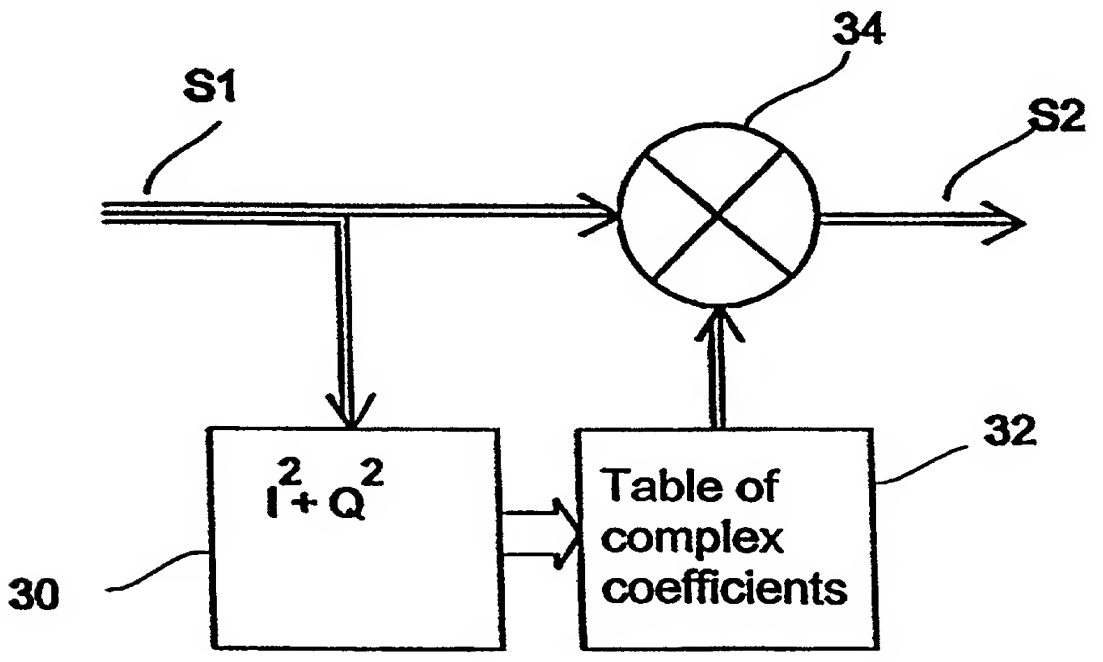

34
S1
S2
32
I^2+Q^2
Table of complex coefficients
30

Fig. 2

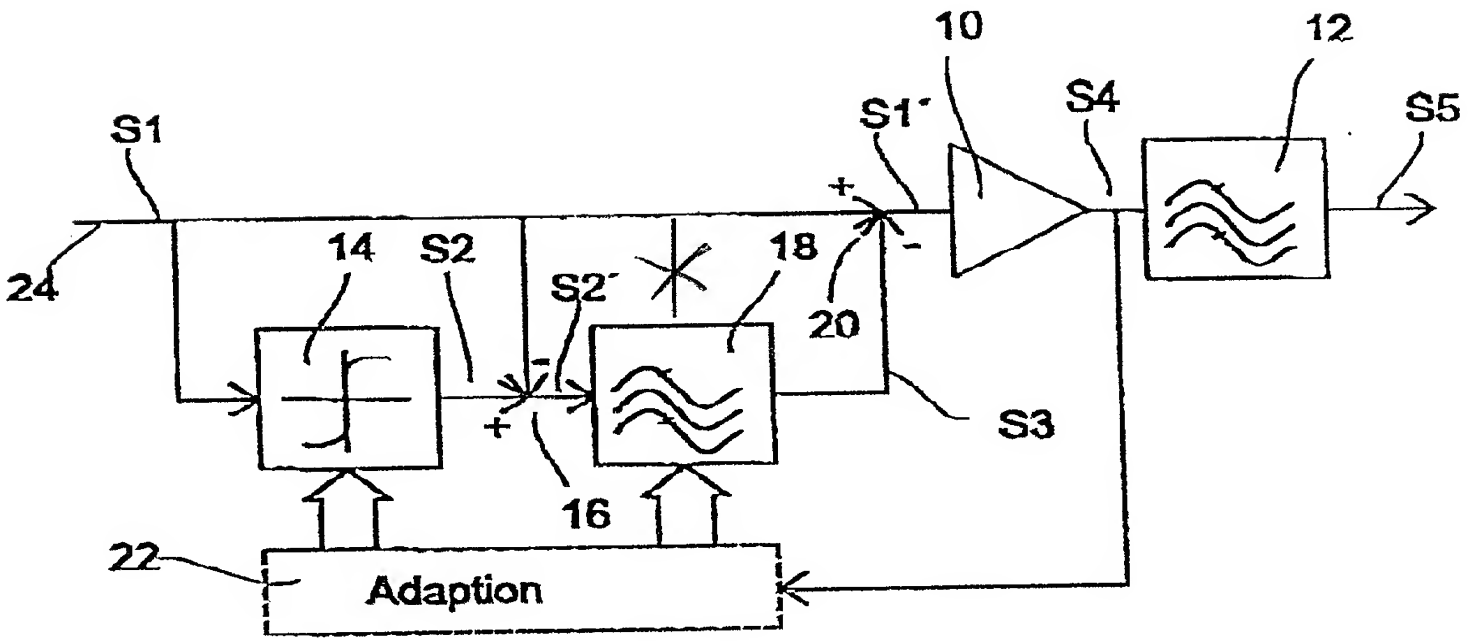

10
12
S1
S1'
S4
S5
+
-
24
14
S2
S2'
18
20
-
+
S3
16
22
Adaption

Fig. 1

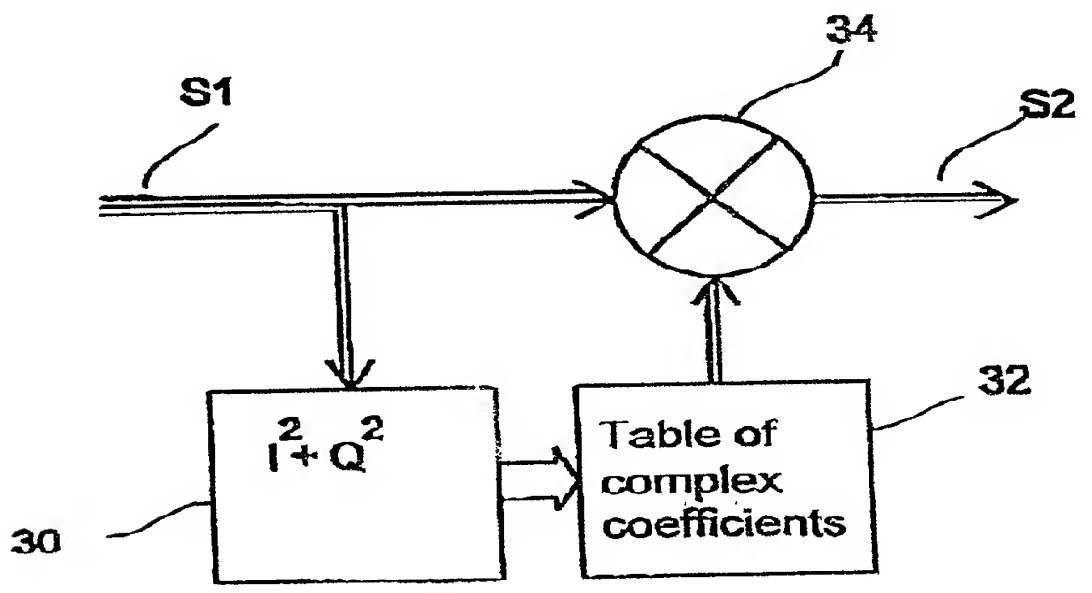

34
S1
S2
32
I^2+Q^2
Table of complex coefficients
30

Fig. 2

VERSION WITH MARKINGS TO SHOW CHANGES MADE

In the Specification:

On page 1, after the title, please delete the heading "Description" and substitute therefor --Background of the Invention--, and the sub-heading --Field of the Invention--:

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a device and a method for predistorting signals to be transmitted over a nonlinear transmission path in such a way that the influence of interference segments on the useful part of the signal transmitted over the nonlinear transmission path can be optimized. The present invention may preferably be employed in transmitters for digital broadcasting, which are supplied with signals composed of a number of single carriers and which result in a non-constant envelope of a high-frequency carrier signal. It is particularly in the case of such signals that the nonlinearity of the power amplifier of an output stage of the transmitter gives rise to undesirable frequencies in the signal at the output of the power amplifier which disturb neighbouring frequency channels.

On page 2, at line 29, please insert the following heading: --Description of Prior Art--.

Description of Prior Art

In digital predistortion of a signal to be transmitted, the digitally represented values of the signal are multiplied by suitably chosen coefficients. The predistortion thus takes place together with the digital generation of the control signal of the modulator.

On page 9, at line 16, before the paragraph beginning "It is the object …", please insert the heading --Summary of the Invention--.

Summary of the Invention

It is the object of the present invention to provide a novel device and a novel method for predistorting a transmission signal to be transmitted over a nonlinear transmission path which permit a predistortion of the signal to be transmitted such that the influence on the useful part of the signal of interference segments produced by a nonlinear transmission path can be minimized and also to provide a high-frequency transmitter and a method for the

spectral shaping of an interference spectrum of a transmission signal using such a device and such a method.

On page 10, in the "Summary of the Invention" section, please amend paragraphs one and two to be combined into one paragraph, to read as follows:

[This object is achieved by a device according to claim 1, a high-frequency transmitter according to claim 10 and methods according to claims 11 and 12.

The present invention provides a device for predistorting a transmission signal to be transmitted over a nonlinear transmission path which has an estimator for determining an error signal depending on the transmission signal and on a previously registered transfer characteristic of the nonlinear transmission path. The error signal represents an estimate of an error generated by the nonlinearity of the transmission path. A time-dispersive element is provided to generate a correction signal through temporal extension of the error signal. The correction signal is combined with the transmission signal in a combiner. As a result of the temporal extension of the error signal an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the transmission signal.]

According to a first aspect of the present invention this object is achieved by a device for predistorting a transmission signal to be transmitted over a nonlinear trans-mission path which has an estimator for determining an error signal depending on the transmission signal and on a previously registered transfer characteristic of the nonlinear transmission path. The error signal represents an estimate of an error generated by the nonlinearity of the transmission path. A time-dispersive element is provided to generate a correction signal through temporal extension of the error signal. The correction signal is combined with the transmission signal in a combiner. As a result of the temporal extension of the error signal an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the transmission signal.

On page 10 following the above-amended paragraph, please insert the following new paragraphs:

According to a second aspect of the present invention this object is achieved by a high-frequency transmitter comprising:

a predistorter for predistorting a transmission signal to be transmitted over a nonlinear transmission path, said predistorter comprising:

an estimator for determining an error signal depending on the transmission signal and a previously registered transfer characteristic of the nonlinear transmission path, where the error signal represents an estimate of an error generated due to the nonlinearity of the transmission path;

a time-dispersive element for generating a correction signal by a temporal extension of the error signal; and

a combiner for combining the transmission signal and the correction signal,

wherein, due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the signal;

a power amplifier for amplifying a transmission signal which has been predistorted by the predistorter; and

a bandpass filter which succeeds the power amplifier and whose transmission band is adjusted to the useful frequency range of the transmission signal.

According to a third aspect of the present invention this object is achieved by a method for predistorting a transmission signal to be transmitted over a nonlinear transmission path, comprising the following steps:

generating an error signal from the transmission signal to be transmitted and a previously registered transfer characteristic of the nonlinear transmission path, wherein the error signal represents an estimate of an error generated due to the nonlinearity of the transmission path;

effecting a temporal extension of the error signal to generate a correction signal;

combining the correction signal and the transmission signal to be transmitted to generate a predistorted transmission signal,

wherein, due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the transmission signal.

According to a fourth aspect this object is achieved by a method for spectrally forming an interference spectrum of a transmission signal at the output of a power transmitter, said method comprising the steps of:

generating an error signal from the transmission signal and a previously registered transfer characteristic of a power amplifier, wherein the error signal represents an estimate of an error generated due to a nonlinearity of the power amplifier;

effecting a temporal extension of the error signal to generate a correction signal;

combining the correction signal and the transmission signal to generate a predistorted transmission signal,

wherein , due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the power amplifier is shifted away from the useful frequency range of the transmission signal; and

feeding the predistorted transmission signal (S1') into the power amplifier.

On page 13, at line 24, before the paragraph beginning "Preferred Embodiments of the Present Invention ...,: please insert the heading --Brief Description of the Drawings--.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present invention are described in more detail below making reference to the drawings, in which:

On page 14, at line 9, after the description of Fig. 5 and 6, please insert the heading --Description of Preferred Embodiments of the Invention--.

DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

A preferred embodiment of the present invention will now be described in terms of a transmitter which features a high-frequency power amplifier. It is clear, however, that the present invention can also be employed to predistort signals transmitted over other nonlinear transmission paths.

In the Claims:

1. (Once Amended) A device for predistorting a transmission signal [(S1)] to be transmitted over a nonlinear transmission path [(10)], comprising:

an estimator [(14, 16)] for determining an error signal [(S2')] depending on the transmission signal [(S1)] and a previously registered transfer characteristic of the nonlinear transmission path[(10)], where the error signal [(S2')]represents an estimate of an error generated due to the nonlinearity of the transmission path[(10)];

a time-dispersive element [(18)]for generating a correction signal [(S3)]by a temporal extension of the error signal[(S2')]; and

a combiner for combining the transmission signal [(S1)]and the correction signal[(S3)],

wherein, due to the temporal extension of the error signal[(S2')], an error signal segment [(50, 52)]in the frequency spectrum of a transmission signal [(S4)]transmitted by the nonlinear transmission path [(10)]is shifted away from the useful frequency range [(60)]of the signal.

2. (Once Amended) A device according to claim 1, wherein the nonlinear transmission path[(10)] is a power amplifier.

3. (Once Amended) A device according to claim 1[or 2], wherein the estimator [(14, 16)]has a unit [(30)]for forming the squares of the magnitudes of the transmission signal [(S1)]to be transmitted and a table [(32)]for supplying complex distortion coefficients, which depend on the squares of the magnitudes and on the previously registered transfer characteristic of the nonlinear transmission path[(10)].

4. (Once Amended) A device according to claim 3, wherein the unit [(30)]for forming the squares of the magnitudes of the real and the imaginary part of the transmission signal is provided.

5. (Once Amended) A device according to claim 1[or 2], wherein the estimator has an envelope detector for detecting the envelope of the transmission signal, a quantizer for forming quantized envelope values and a table unit for supplying complex distortion coefficients which depend on the quantized envelope values and on the previously registered transfer characteristic of the nonlinear trans-mission path.

6. (Once Amended) A device according to [one of the]claim[s] 3[to 5], wherein the estimator also includes a unit for combining the squares of the magnitudes or of the envelope values and the complex coefficients for generating the error signal[(S2')].

7. (Once Amended) A device according to [one of the]claim[s] 1[to 6], wherein the time-dispersive element [(18)]is a time-dispersive bandpass filter or low-pass filter.

8. (Once Amended) A device according to claim 7, wherein an adapter [(22)]is provided which, on the basis of a signal to be transmitted and an output signal output by a nonlinear transmission path [(10)]if there is no predistortion, ascertains the transfer characteristic of the nonlinear transmission path [(10)]and uses this to control the estimator and/or the filter coefficients of the time-dispersive bandpass filter or low-pass filter[(18)].

9. (Once Amended) A device according to claim 8, wherein the adapter [(22)]ascertains the transfer characteristic at predetermined times.

10. (Once Amended) A high-frequency transmitter comprising:

a predistorter [according to one of the claims 1 to 9;]<u>for predistorting a transmission signal to be transmitted over a nonlinear transmission path, said predistorter comprising:</u>

<u>an estimator for determining an error signal depending on the transmission signal and a previously registered transfer characteristic of the nonlinear transmission path, where the error signal represents an estimate of an error generated due to the nonlinearity of the transmission path;</u>

a time-dispersive element for generating a correction signal by a temporal extension of the error signal; and

a combiner for combining the transmission signal and the correction signal,

wherein, due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the signal according to one of the claims 1 to 9;

a power amplifier [(10)]for amplifying a transmission signal [(S1')]which has been predistorted by the predistorter; and

a bandpass filter [(12)]which succeeds the power amplifier [(10)]and whose transmission band is adjusted to the useful frequency range [(60)]of the transmission signal.

11. (Once Amended) A method for predistorting a transmission signal to be transmitted over a nonlinear transmission path, comprising the following steps:

generating an error signal [(S2')]from the transmission signal [(S1)]to be transmitted and a previously registered transfer characteristic of the nonlinear transmission path[(10)], wherein the error signal [(S2')]represents an estimate of an error generated due to the nonlinearity of the transmission path [(10)];

effecting a temporal extension of the error signal [(S2')]to generate a correction signal[(S3)];

combining the correction signal [(S3)]and the transmission signal [(S1)]to be transmitted to generate a predistorted transmission signal[(S1')],

wherein, due to the temporal extension of the error signal[(S2')], an error signal segment [(50, 52)] in the frequency spectrum of a transmission signal[(S4)] transmitted by the nonlinear transmission path [(10)]is shifted away from the useful frequency range[(60)] of the trans-mission signal.

12. (Once Amended) A method for spectrally forming an interference spectrum of a transmission signal at the output of a power transmitter, said method comprising the

steps of: [which, in addition to performing the method according to claim 11, wherein the nonlinear transmission path is a power amplifier, also includes the step of]

generating an error signal from the transmission signal and a previously registered transfer characteristic of a power amplifier, wherein the error signal represents an estimate of an error generated due to a nonlinearity of the power amplifier;

effecting a temporal extension of the error signal to generate a correction signal;

combining the correction signal and the transmission signal to generate a predistorted transmission signal,

wherein , due to the temporal extension of the error signal, an error signal segment in the frequency spectrum of a transmission signal transmitted by the power amplifier is shifted away from the useful frequency range of the transmission signal; and

feeding the predistorted transmission signal [(S1')]into the power amplifier.

13. (Once Amended) A method according to claim 12, which also includes the step of performing bandpass filtering of an output signal [(S4)]output by the power amplifier.

In the Abstract:

A device for predistorting a transmission signal [(S1)] to be transmitted over a nonlinear transmission path [(10)] comprises an estimator [(14, 16)] for determining an error signal [(S2')] depending on the transmission signal [(S1)] and a previously registered transfer characteristic of the nonlinear transmission path[(10)]. The error signal [(S2')] represents an estimate of an error generated due to the nonlinearity of the transmission path [(10)]. A time-dispersive element[(18)] is provided to produce a correction signal[(S3)] by a temporal extension of the error signal[(S2')]. A combiner[(20)] is provided to combine the transmission signal [(S1)]and the correction signal[(S3)]. As a result of the temporal extension of the error signal[(S2')], an error signal segment in the frequency spectrum of a transmission signal [(S4)]transmitted by the nonlinear transmission path [(10)]is shifted away from the useful frequency range of the transmission signal.

Device and Method for Predistorting a Transmission Signal to be Transmitted Via a Nonlinear Transmission Path

Description

The present invention relates to a device and a method for predistorting signals to be transmitted over a nonlinear transmission path in such a way that the influence of interference segments on the useful part of the signal transmitted over the nonlinear transmission path can be optimized. The present invention may preferably be employed in transmitters for digital broadcasting, which are supplied with signals composed of a number of single carriers and which result in a non-constant envelope of a high-frequency carrier signal. It is particularly in the case of such signals that the nonlinearity of the power amplifier of an output stage of the transmitter gives rise to undesirable frequencies in the signal at the output of the power amplifier which disturb neighbouring frequency channels.

If modulation methods which lead to a non-constant envelope for the high-frequency carrier signal are used in e.g. a wireless communication system, all the signal processing components after the modulator must possess sufficient linearity. This requirement is particularly difficult to fulfil in the case of power amplifier stages designed to operate with high efficiency.

When pulse amplitude modulation methods are employed, the spectral efficiency is degraded by the nonlinearity of the amplifiers. The reason for this is to be found in the nonlinear amplitude output characteristics of an amplifier, which

leads to an AM/AM conversion. Furthermore, the drift in the phase of an output signal of an amplifier compared with the phase of an input signal generates intermodulation components, which is also referred to as AM/PM conversion. The AM/AM and AM/PM conversions must be eliminated by suitable linearization methods. If this is not done, the spectral efficiency of the modulation method employed and the signal/noise ratio will be degraded. In digital transmission systems this can result in a considerable increase in the transmission bit error rate.

There thus exists the need for a suitable linearization method based on predistortion. This could be employed in all cases where in general a nonlinear transmission path is to be linearized. The linearization of a nonlinear transmission path should also permit the frequency range of the input signal into the nonlinear transmission path which is to be equalized to differ from the frequency range of the output signal from the nonlinear transmission path. The linearization must not be restricted purely to amplifier stages, therefore, but it must also be possible to perform frequency conversions within the nonlinear transmission path.

Many methods for linearizing high-frequency output stages are already known in this field of technology. The best known methods for linearizing high-frequency output stages are listed below.

In digital predistortion of a signal to be transmitted, the digitally represented values of the signal are multiplied by suitably chosen coefficients. The predistortion thus takes place together with the digital generation of the control signal of the modulator.

Another known method is analog predistortion. This employs nonlinear components, e.g. Schottky diodes, to synthesize an equalization characteristic which is the complement of the amplifier distortion characteristic.

The "Cartesian loop" represents an analog negative feedback of the high-frequency output stage which is performed in the baseband.

Forward coupling (also called "feedforward") represents a disturbance-variable insertion in the sense of control engineering, a corresponding correction voltage being added to the output signal of the output stage so as to compensate for the distortion of the output stage.

In WO 93/18581 a "Cartesian loop" is described whose parameters are adjusted according to various system parameters which reflect the current operating state of the system. Here a radio transmitter comprises a power amplifier, a linearizer and a feedback device for feeding a signal from an output of the power amplifier back to the linearizer so as to ensure the linearity of the output signal. The linearizer operates in the baseband and the IQ signals are controlled by a linear control which is associated with a direct-access table which stores predetermined loop linearization parameters. After the IQ signals have been suitably processed by the linearizer, these processed signals are up-converted by an up-converter and are amplified by the power amplifier. The feedback device takes an output signal of the power amplifier, down-converts it by means of a down-converter and feeds the down-converted signal into the linearizer. The linearization does not therefore take place in the high-frequency range but in the base-

band range, since use is made of the IQ signals. Furthermore, the circuit described provides a permanent negative feedback of the high-frequency output stage in the sense of a Cartesian loop.

GB 2240893 A discloses a circuit for linearizing the amplitude response and the phase response of an amplifier. An envelope detector circuit detects the envelope of an input signal to be transmitted and the output signal of the envelope detector circuit is fed into a nonlinear control circuit and into a phase shifter control circuit. The phase shifter control circuit controls a phase shifter, which precedes the power amplifier, so as to predistort the high-frequency signal phasewise. The nonlinear control circuit supplies an input signal to a variable-voltage dc-dc converter, which suitably adjusts the bias voltage parameters, i.e. the operating point of the power amplifier, so as to compensate for the distortion of the nonlinear amplifier. The amplitude error of the amplifier is thus compensated for by adjusting its operating point, which has the disadvantage that the operating point parameters of the amplifier have to be changed continually, which can make it very difficult to match the amplifier to a load since changing the operating point normally automatically entails a different (complex) transformation relationship for the output resistance.

US Patent No. 5,023,937 describes an analog predistortion circuit for a power amplifier which is operated in the nonlinear range. This predistortion operates by means of a negative feedback loop in which, in contrast to the Cartesian loop, the magnitude and phase of the output signal and not the IQ components are controlled. An envelope detector detects the amplitude of the signal to be amplified and this

amplitude, via feedback, is continuously compared with the envelope of the output signal of the power amplifier. The result of the comparison is applied to a variable attenuator which suitably attenuates the input signal to the power amplifier so as to generate an output signal which is as nearly linear as possible. The phase predistortion is performed by means of a phase-locked loop which has the signal to be amplified as its input signal. Part of the output signal of the amplifier is also fed, via a converter, a local oscillator and a phase shifter circuit, into the phase-locked loop, which supplies a local oscillator signal for a converter which precedes the power amplifier and predistorts the phase of the signal to be amplified. The operation of this circuit is completely analog and is based on an essentially continuous feedback provided the phase-locked loop is locked.

US Patent No. 4,465,980 also describes an analog predistortion circuit. A detector detects the envelope of a signal to be amplified and applies this signal to a field-effect transistor having two gate terminals (dual gate FET). The signal to be amplified is applied to the other gate of the dual gate FET. By suitably controlling the operating point of this dual gate FET the HF input signal is suitably predistorted so as to compensate for the nonlinear amplification of a power amplifier which is connected to the drain terminal of the dual gate FET via a matching network.

DE 3312030 A1 discloses an amplifier with predistortion compensation which employs predistortion components generated by a power amplification element similar to the amplification element so as to achieve an effective linearization which substantially reduces all the intermodulation predistortion

products. Furthermore, an additional feedback circuit can also be provided to reduce nonlinearities still further.

EP 312261 A2 discloses a linearization correction circuit which operates in an intermediate frequency range so as to introduce suitable predistortion into an amplitude envelope to compensate for the nonlinearity of the power amplifier stages. An array of parallel current sources, each of which can be adjusted via a corresponding amplitude band in reaction to a predistortion, injects a current which is sufficient to introduce a suitable difference voltage at the output. With this circuit there is obviously no phase predistortion.

EP 0 658 975 A1 relates to a baseband predistortion system for the adaptive linearization of power amplifiers and to a radio transmitter which uses the predistortion system. Here two error tables, one for the amplitude and one for the phase, are actualized and the contents thereof are used to correct the baseband sampled values. The contents of the tables are obtained by accumulating a suitably weighted difference between sampled values, which are fed into the predistortion unit, and a demodulated feedback value. As has already been described for WO93/18581, a predistortion is thus performed not in the high-frequency range but digitally in the baseband. Access to the digital signal conditioning in the baseband must be provided.

A digital predistortion as described in EP 0 658 975 A1 and in WO93/18581 involves access to the modulation signal before it is converted from a digital form to an analog voltage value in order to be able to perform the necessary digital calculations for correcting the carrier amplitude and the

carrier phase. In many cases such access is not available since linearization can only be performed within the closed system of the power output stage.

In the case of analog predistortion of the high-frequency signal there is the problem of having to synthesize a suitable characteristic from nonlinear components which are subject to individual differences, temperature drift, ageing, etc. Ageing of the components may result in increased nonlinearity.

The "Cartesian loop", i.e. a high-frequency negative feedback, reacts very sensitively to parameter fluctuations. As a consequence of the high amplification there is also a strong tendency for the whole arrangement to oscillate if the feedback parameters are not determined precisely. The noise behaviour of the output stage is also seriously degraded by the negative feedback since this introduces uncorrelated noise into the amplifier stage.

The feedforward method requires a precise determination of the signal propagation times of the output stage. The linearization demands made on the correction signal are high, which means that technically advanced, costly power amplifiers must be used in a circuit which performs linearization according to the feedforward method.

A method for the additive correction of an OFDM signal is also known from the article "Reduktion von Nachbarkanalstörungen in OFDM-Funkubertragungssystemen" by Thomas May, Hermann Rohling, TU Braunschweig, Schleinitzstrasse 22, 38092 Braunschweig. In this method the OFDM baseband signal is corrected by means of a suitable auxiliary function to counter-

act nonlinearities caused by a subsequent amplifier. The auxiliary function is a suitably adapted si function which ensures that there is no adjacent channel interference since the interference power is concentrated on the OFDM bandwidth so that there is practically no out-of-band radiation.

Also known from DE 19631388 A1 is a system for predistortion for a nonlinear transmission path in the high-frequency range where the envelope of a signal to be transmitted over a nonlinear transmission path is detected, whereupon quantized envelope values are formed. Complex predistortion coefficients, which depend on the quantized envelope values and on a transfer function of the nonlinear transmission path registered beforehand, are stored in a table unit. In addition an evaluator is provided, e.g. an IQ modulator, via which the signal to be transmitted is modulated with the complex predistortion coefficients prior to transmission of the signal over the nonlinear transmission path in such a way that the predistortion caused by the nonlinear transmission path is substantially compensated for as regards magnitude and phase. It has turned out, however, that complete compensation is scarcely achievable with this system and furthermore interference segments still remain in the immediate neighbourhood of the useful channel of the transmission signal. Much is therefore required of a bandpass filter at the far end of the nonlinear transmission path.

In most of the known methods described above for linearizing high-frequency output stages the aim is to reduce the effect of the nonlinearity of the amplifier by providing it with a suitably predistorted input signal. In this way a nonlinear behaviour of the combination predistorter/amplifier within the permissible dynamic range can be achieved. The known pre-

distorters remember nothing. As soon as the amplifier is so strongly driven for a short time that it acts as a limiter, the predistortion becomes ineffective. The feedforward methods which have also been described represent a disturbance-variable insertion in the sense of control engineering, as already mentioned, a disadvantage being that an amplifier with a
performnce almost equal to that of the amplifier to be linearized is needed to generate the correction signal.

For input signals with a high crest factor, which occur e.g. in multicarrier methods, the known methods are ineffective since the power amplifier momentarily enters the limiting region.

It is the object of the present invention to provide a novel device and a novel method for predistorting a transmission signal to be transmitted over a nonlinear transmission path which permit a predistortion of the signal to be transmitted such that the influence on the useful part of the signal of interference segments produced by a nonlinear transmission path can be minimized and also to provide a high-frequency transmitter and a method for the spectral shaping of an interference spectrum of a transmission signal using such a device and such a method.

This object is achieved by a device according to claim 1, a high-frequency transmitter according to claim 10 and methods according to claims 11 and 12.

The present invention provides a device for predistorting a transmission signal to be transmitted over a nonlinear transmission path which has an estimator for determining an error

signal depending on the transmission signal and on a previously registered transfer characteristic of the nonlinear transmission path. The error signal represents an estimate of an error generated by the nonlinearity of the transmission path. A time-dispersive element is provided to generate a correction signal through temporal extension of the error signal. The correction signal is combined with the transmission signal in a combiner. As a result of the temporal extension of the error signal an error signal segment in the frequency spectrum of a transmission signal transmitted by the nonlinear transmission path is shifted away from the useful frequency range of the transmission signal.

The present invention differs from known proposals in that no attempt is made to avoid limitation of the amplifier by linearizing it. Instead the spectral distribution of the resulting interference is modified in such a way that it can be reduced or minimized quite simply by means of a bandpass filter following the amplifier. The predistortion according to the present invention thus effects a spectral shaping of the interference spectrum at the output of a nonlinear transmission path. The present invention is particularly suitable for use in transmitters used to transmit signals modulated by multicarrier methods, e.g. transmitters for digital broadcasting. In such transmitters the bandpass filter referred to above is normally already present at the output of the power amplifier.

According to the present invention the shaping of the interference spectrum at the output of a nonlinear transmission path is achieved in that an estimate is first made of the error signal caused by the nonlinear transmission path, whereupon the estimated error signal is subjected to a temporal

extension prior to combining it with the signal to be transmitted. Through this temporal extension interference signal segments in the frequency spectrum of the output signal of the nonlinear transmission path are shifted into a desired spectral range which is displaced from the frequency range of the useful signal.

The present invention is particularly suitable for the predistortion of signals subjected to multicarrier modulation, but it can also be used for other signals, e.g. CDMA signals, which have high crest factors.

With the present invention the energy of the error signal at the output of the nonlinear transmission path can be reduced to a minimum and the remaining energy of the error signal can appear in a desired spectral range which is shifted relative to the frequency range of the useful signal. By employing a bandpass filter at the output of the nonlinear transmission path it is thus possible with the present invention to obtain a transmission signal whose useful part is essentially free from interference segments caused by nonlinearities of the nonlinear transmission path.

Estimating the error signal, which represents an estimate of the error generated by the nonlinearity of the transmission path, can be effected in different ways. For example, it is possible to form squares of the magnitudes of the transmission signal to be transmitted. These provide the basis for accessing a table in which complex distortion coefficients are stored which depend on the squares of the magnitudes and the previously registered transfer characteristics of the nonlinear transmission path. The corresponding distortion coefficients are then combined with the transmission signal to

be transmitted so as to generate the error signal. Alternatively an envelope detector for detecting the envelope of the transmission signal and a quantizer for forming quantized envelope values may be provided. These quantized envelope values again form the basis for accessing a table in which complex distortion coefficients are stored.

In the present invention the time-dispersive element is preferably a time-dispersive bandpass filter or low-pass filter in which short interference pulses are reshaped into longer interference pulses to achieve a temporal extension of the error signal. This extension then determines the spectral shaping of the interference spectrum at the output of the nonlinear transmission path as described above.

The filter coefficients of the time-dispersive bandpass filter or low-pass filter can preferably be determined in advance from the transfer characteristic of the nonlinear transmission path, e.g. by measuring the spectral power of the signal transmitted over the nonlinear transmission path and then using the power in the regions adjoining the useful frequency range as optimization criteria for the filter coefficients. Optimization of the filter coefficients can be effected using known algorithms such as e.g. the simplex algorithm. Apart from the time-dispersive bandpass filter or low-pass filter used as the preferred embodiment, other time-dispersive elements which produce a temporal extension of the estimated error signal may equally well be used.

In preferred embodiments of the present invention the transfer characteristics of the nonlinear transmission path are determined outside the operation of the predistortion device and are then used during operation to set the estimator

and/or the time-dispersive element. To permit fine-tuning at particular times during operation of the predistortion device, an adapter can be provided in the present invention which enables the complex correction coefficients for the estimator or the filter coefficients for the time-dispersive filter to be adjusted to match the prevailing conditions.

The present invention provides a number of advantages over known predistortion systems. For one thing, all the signal processing can be performed digitally, so that there are no component tolerance or adjustment problems. Also, there is no need to tamper with the high-frequency part, i.e. the power amplifier or the bandpass filter which follows this. The reduced spurious emission achieved by the present invention means that substantial savings can be made as regards the power amplifier and its power supply since both can be made smaller. In addition to this, less stringent demands are made on the bandpass filter, which again lowers the costs. Compared with classical linearization methods substantially higher linearization gains in the order of 20 dB can be achieved with the present invention, as opposed to linearization gains of 5 to 8 dB with classical linearization methods.

Preferred embodiments of the present invention are described in more detail below making reference to the drawings, in which:

Fig. 1 shows a schematic block diagram of a transmitter, wherein the predistortion device according to the present invention is used;

Fig. 2 shows a schematic block diagram, which shows an embodiment of an estimator;

Fig. 3 and 4 show time profiles of signals which occur when performing predistortion according to the present invention;

Fig. 5 and 6 show power spectra of signals which occur when performing predistortion according to the present invention.

A preferred embodiment of the present invention will now be described in terms of a transmitter which features a high-frequency power amplifier. It is clear, however, that the present invention can also be employed to predistort signals transmitted over other nonlinear transmission paths.

Fig. 1 shows a transmitter which might be used e.g. for digital broadcasting. An input signal S1, which might be a multi-carrier signal with a non-constant envelope, is fed into the transmitter. Without predistortion this input signal S1 would be fed directly into a power amplifier 10, which is followed by a narrow bandpass filter 12. However, in order to compensate for nonlinearities of the power amplifier 10, which represents a nonlinear transmission path, the input signal S1 is first predistorted. The input signal S1 is therefore first fed into an emulator 14 which emulates the nonlinear behaviour of the power amplifier 10, i.e. an AM/AM and an AM/PM conversion. The resulting signal S2 at the output of the emulator 14 represents an estimate of the signal actually supplied by the power amplifier 10 when the signal S1 is applied to it as input signal. Examples of the emulator 14 will be described below making reference to Fig. 2.

In the embodiment shown the output of the emulator 14 is connected to a combiner, shown schematically at 16 in Fig. 1. The emulator 14 and the combiner 16 represent the estimator of the predistorter according to the present invention in the embodiment shown. In the combiner the input signal S1 and the estimated signal are combined in such a way that an error signal S2′ at the output of the combiner 16 represents an estimate of the error introduced by the power amplifier 10. In the embodiment shown the input signal S1 is subtracted from the estimated signal S2. The output of the combiner 16 is connected to the input of a time-dispersive filter 18. The time-dispersive filter 18 generates through temporal extension of the error signal S2′ a correction signal S3. This correction signal S3 is combined with the input signal S1 in a further combiner, shown schematically at 20 in Fig. 1. In the embodiment shown the correction signal S3 is subtracted from the input signal S1. Whether a subtraction or addition is performed in the combination element depends on the filter coefficients of the time-dispersive bandpass filter or lowpass filter 18.

The output of the combiner 20 is connected to the input of the power amplifier 10. The power amplifier 10 thus amplifies the predistorted signal S1′ formed by combining the input signal S1 and the correction signal S3. The signal S4 at the output of the power amplifier 10 then undergoes bandpass filtering by the bandpass filter 12 to generate the output signal S5 of the transmitter.

As is also shown in Fig. 1, an adaption device 22 can optionally be provided which captures the signal S4 output by the power amplifier 10 and uses it to determine transfer charac-

teristics of the power amplifier 10 and to adapt the emulator 14 and the time-dispersive bandpass filter or low-pass filter 18. In addition, suitable delay elements can be incorporated in the direct signal path from the input 24 of the transmitter to the combiner 20 to compensate for the already known delay time of the predistortion according to the present invention. The predistortion is preferably synchronized by an external clock so that the delay time does not depend on parameters of any kind. In this way it is possible to compensate simply for the delay time by providing suitable delay elements in the direct path between the input 24 and the combiner 20.

Before discussing the mode of operation of the predistorter shown in Fig. 1 making reference to Fig. 3 to 6, a preferred embodiment of the emulator 14 will first be described making reference to Fig. 2.

In the preferred embodiment the emulator 14 has a unit 30 for forming the squares of the magnitudes which is supplied with the input signal S1. The unit 30 forms the sum of the squares of the magnitudes of the real part I^2 and the imaginary part Q^2 of the input signal S1. On the basis of these squares a table 32 of complex coefficients is accessed in which complex coefficients allocated to the squares or the sum of the squares are stored. The input signal S1 is then multiplied with these
complex coefficients according to the rules for complex numbers in a complex-number multiplier 34. The complex-number multiplier 34 may e.g. be an IQ modulator. The estimated signal S2 appears at the output of the complex-number multiplier 34.

The complex coefficients of table 32 are calculated and stored on the basis of the transfer characteristic of the power amplifier 10 outside the operation of the circuit. The circuit shown in Fig. 2 thus simulates the transfer characteristic of the power amplifier 10, so that the signal S2 represents an estimate of the signal which would be obtained through the power amplifier 10 if it were fed with a non-predistorted input signal S1. To obtain an error signal which represents an estimate of the error generated by the power amplifier 10 the signal S2 is combined with the signal S1, so the emulator 14 together with the combiner 16 can be regarded as an estimator for estimating the error signal.

Alternatively, the complex coefficients in the table can be so adjusted that by multiplying them directly with the signal to be transmitted a signal is output which describes the error generated by the power amplifier 10 and thus corresponds to the error signal S2'.

As an alternative to the unit for forming the squares of the magnitudes described above, an envelope detector and a quantizer for forming quantized envelope values from the detected envelope can be provided. In this case the table of complex coefficients is then accessed on the basis of the quantized envelope values. The envelope detector could be e.g. a diode rectifier and the quantizer could be e.g. an analog/digital converter.

The adaption device 22 shown in Fig. 1 can serve to produce adaptively both the coefficients of the filter 18 and the complex coefficients of table 32. The power of the spurious emission in the desired frequency range can be used to provide the optimization criterion for optimizing the filter co-

efficients of the time-dispersive filter. The output signal of the power amplifier 10 when the predistorter is not active can be used to generate the complex coefficients for the table 32 of the emulator 14. The filter coefficients of the time-dispersive filter 18 can also be ascertained from the output signals of the power amplifier 10 and the associated input signals when the predistorter or at least the time-dispersive filter is not active. A means of bypassing the time-dispersive filter 18 can be provided for this purpose.

The adapter 22 can also be designed so as to perform fine-tuning of the complex coefficients or filter coefficients at particular times during operation. In this case a comparator can be optionally provided which compares the input signal S1 and the output signal S4 so as to establish whether there is a linear relationship, e.g. a simple amplification, between them. If the relationship is not linear, this indicates that the ambient conditions have changed, which means that the distortion coefficients no longer have their optimal values. In a recalibration step the adapter can then access the emulator 14 and the time-dispersive filter 18 so as to appropriately modify the complex coefficients in table 32 and/or the filter coefficients of the time-dispersive filter 18.

the mode of operation of the circuit shown in Fig. 1 will now be described in more detail referring to the signal profiles in Fig. 3 to 6.

Fig. 3 shows the way in which the envelopes of a typical multicarrier signal which represents the input signal S1 vary with time (|U|, t). The numbers on the time axis represent sampled values. As can be seen from Fig. 3, the input signal S1 has a high crest factor, which for normal operation of the

power amplifier 10 is large enough to bring the amplifier fully into the limitation region, so that traditional linearization is completely ineffective.

From this input signal S1 the emulator 14 and the combiner 16, which together constitute the estimator, produce a signal S2-S1, whose time profile is also shown in Fig. 3 and which represents the error signal S2'. This error signal S2' is reproduced somewhat magnified in Fig. 4. The error signal S2' is fed into the time-dispersive element where temporal extension of the signal takes place, resulting in the signal S3, also shown in Fig. 4. As can clearly be seen in Fig. 4, the signal S3 is temporally extended with respect to the error signal S2'. As described above, this correction signal S3 is now combined with the input signal S1, thus generating a predistorted input signal S1'. This predistorted input signal S1' is then fed into the nonlinear power amplifier 10. The spectrum of the output signal S4 of the power amplifier 10 is shown in Fig. 5. The unit used for the horizontal axis in Fig. 5 and in Fig. 6 is the relative frequency in terms of the centre frequency of a useful channel.

In Fig. 5 the spectrum of the signal S2 which would appear at the output of the power amplifier 10 without predistortion is shown for comparison. It can clearly be seen that the interference power of the signal S4 outside the useful range 60 is reduced compared with the signal S2 and is also distributed differently. In the embodiment shown the useful range lies between the relative frequencies of about -100 and about 100. The remaining interference segments 50 and 52 of the signal S4 fall outside this useful range, being separated from it by the intervening regions 54 and 56. This shifting of the interference segments 50 and 52 away from the useful range re-

sults from the temporal extension of the error signal S2' to generate the correction signal S3. This is particularly apparent in Fig. 6, which again shows the spectrum of the signal S4 and also the spectrum of the correction signal S3. As can be seen, the spectrum of the correction signal S3 has bumps 58 and 60 in the region of the channels directly adjoining the useful channel 60, so that subtracting the signal S3 from the input signal S1 in these regions results in an increased attenuation. As a result the interference segments 50 and 52 are shifted away from the useful frequency range.

The shifting of the interference segments 50 and 52 away from the useful frequency range means that the power amplifier 10 can be followed by a bandpass filter 12 which is subject to less stringent requirements as regards its transmission characteristic than if the interference signal segments were located directly adjacent to the useful frequency range. By shifting the interference signal energy into a desired spectral range outside the useful frequency range and minimizing the energy of the error signal at the output of the power amplifier by estimating the error by means of the estimator, the present invention makes it possible to manufacture relatively cheap transmitters, since both the power amplifier and its power supply can be made smaller and it is possible to use a bandpass filter with less stringent requirements.

Claims

1. A device for predistorting a transmission signal (S1) to be transmitted over a nonlinear transmission path (10), comprising:

an estimator (14, 16) for determining an error signal (S2') depending on the transmission signal (S1) and a previously registered transfer characteristic of the nonlinear transmission path (10), where the error signal (S2') represents an estimate of an error generated due to the nonlinearity of the transmission path (10);

a time-dispersive element (18) for generating a correction signal (S3) by a temporal extension of the error signal (S2'); and

a combiner for combining the transmission signal (S1) and the correction signal (S3),

wherein, due to the temporal extension of the error signal (S2'), an error signal segment (50, 52) in the frequency spectrum of a transmission signal (S4) transmitted by the nonlinear transmission path (10) is shifted away from the useful frequency range (60) of the signal.

2. A device according to claim 1, wherein the nonlinear transmission path (10) is a power amplifier.

3. A device according to claim 1 or 2, wherein the estimator (14, 16) has a unit (30) for forming the squares of the magnitudes of the transmission signal (S1) to be

transmitted and a table (32) for supplying complex distortion coefficients, which depend on the squares of the magnitudes and on the previously registered transfer characteristic of the nonlinear transmission path (10).

4. A device according to claim 3, wherein the unit (30) for forming the squares of the magnitudes of the real and the imaginary part of the transmission signal is provided.

5. A device according to claim 1 or 2, wherein the estimator has an envelope detector for detecting the envelope of the transmission signal, a quantizer for forming quantized envelope values and a table unit for supplying complex distortion coefficients which depend on the quantized envelope values and on the previously registered transfer characteristic of the nonlinear transmission path.

6. A device according to one of the claims 3 to 5, wherein the estimator also includes a unit for combining the squares of the magnitudes or of the envelope values and the complex coefficients for generating the error signal (S2').

7. A device according to one of the claims 1 to 6, wherein the time-dispersive element (18) is a time-dispersive bandpass filter or low-pass filter.

8. A device according to claim 7, wherein an adapter (22) is provided which, on the basis of a signal to be transmitted and an output signal output by a nonlinear

transmission path (10) if there is no predistortion, ascertains the transfer characteristic of the nonlinear transmission path (10) and uses this to control the estimator and/or the filter coefficients of the time-dispersive bandpass filter or low-pass filter (18).

9. A device according to claim 8, wherein the adapter (22) ascertains the transfer characteristic at predetermined times.

10. A high-frequency transmitter comprising:

a predistorter according to one of the claims 1 to 9;

a power amplifier (10) for amplifying a transmission signal (S1') which has been predistorted by the predistorter; and

a bandpass filter (12) which succeeds the power amplifier (10) and whose transmission band is adjusted to the useful frequency range (60) of the transmission signal.

11. A method for predistorting a transmission signal to be transmitted over a nonlinear transmission path, comprising the following steps:

generating an error signal (S2') from the transmission signal (S1) to be transmitted and a previously registered transfer characteristic of the nonlinear transmission path (10), wherein the error signal (S2') represents an estimate of an error generated due to the nonlinearity of the transmission path (10);

effecting a temporal extension of the error signal (S2') to generate a correction signal (S3);

combining the correction signal (S3) and the transmission signal (S1) to be transmitted to generate a predistorted transmission signal (S1'),

wherein, due to the temporal extension of the error signal (S2'), an error signal segment (50, 52) in the frequency spectrum of a transmission signal (S4) transmitted by the nonlinear transmission path (10) is shifted away from the useful frequency range (60) of the transmission signal.

12. A method for spectrally forming an interference spectrum of a transmission signal at the output of a power transmitter which, in addition to performing the method according to claim 11, wherein the nonlinear transmission path is a power amplifier, also includes the step of feeding the predistorted transmission signal (S1') into the power amplifier.

13. A method according to claim 12, which also includes the step of performing bandpass filtering of an output signal (S4) output by the power amplifier.

Device and Method for Predistorting a Transmission Signal to be Transmitted Via a Nonlinear Transmission Path

Abstract

A device for predistorting a transmission signal (S1) to be transmitted over a nonlinear transmission path (10) comprises an estimator (14, 16) for determining an error signal (S2') depending on the transmission signal (S1) and a previously registered transfer characteristic of the nonlinear transmission path (10). The error signal (S2') represents an estimate of an error generated due to the nonlinearity of the transmission path (10). A time-dispersive element (18) is provided to produce a correction signal (S3) by a temporal extension of the error signal (S2'). A combiner (20) is provided to combine the transmission signal (S1) and the correction signal (S3). As a result of the temporal extension of the error signal (S2'), an error signal segment in the frequency spectrum of a transmission signal (S4) transmitted by the nonlinear transmission path (10) is shifted away from the useful frequency range of the transmission signal.

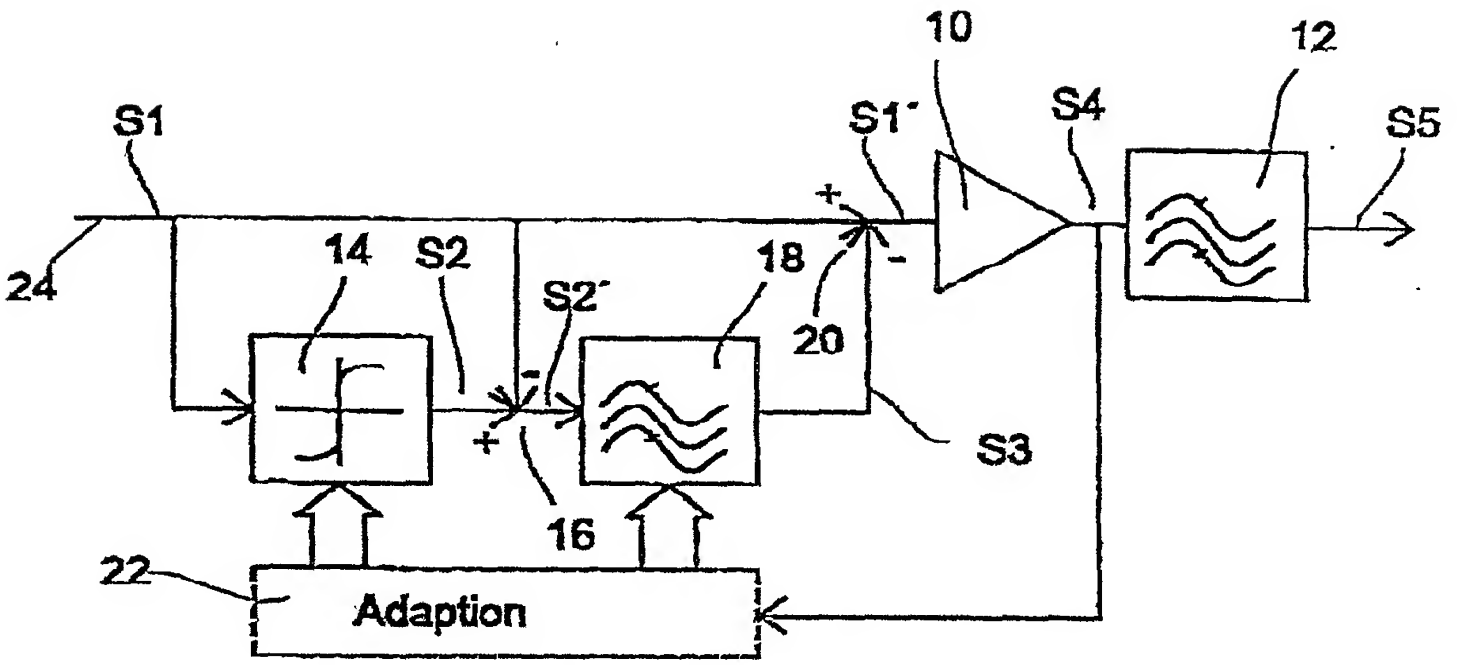

10
12
S1
S1'
S4
S5
+
-
24
14
S2
S2'
18
20
-
+
S3
16
22
Adaption

Fig. 1

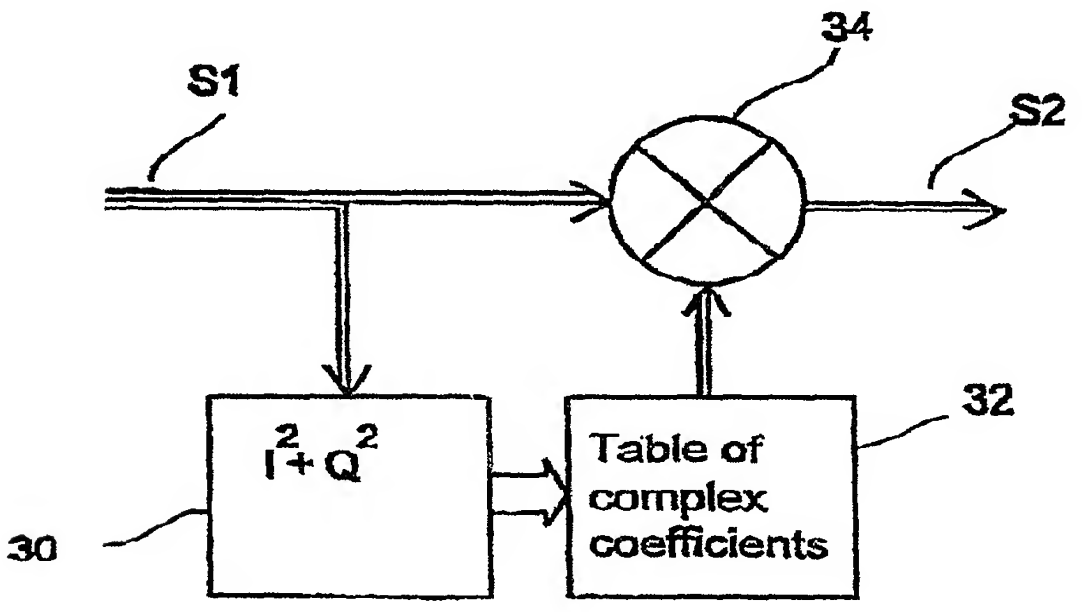

34
S1
S2
32
I^2+Q^2
Table of complex coefficients
30

Fig. 2

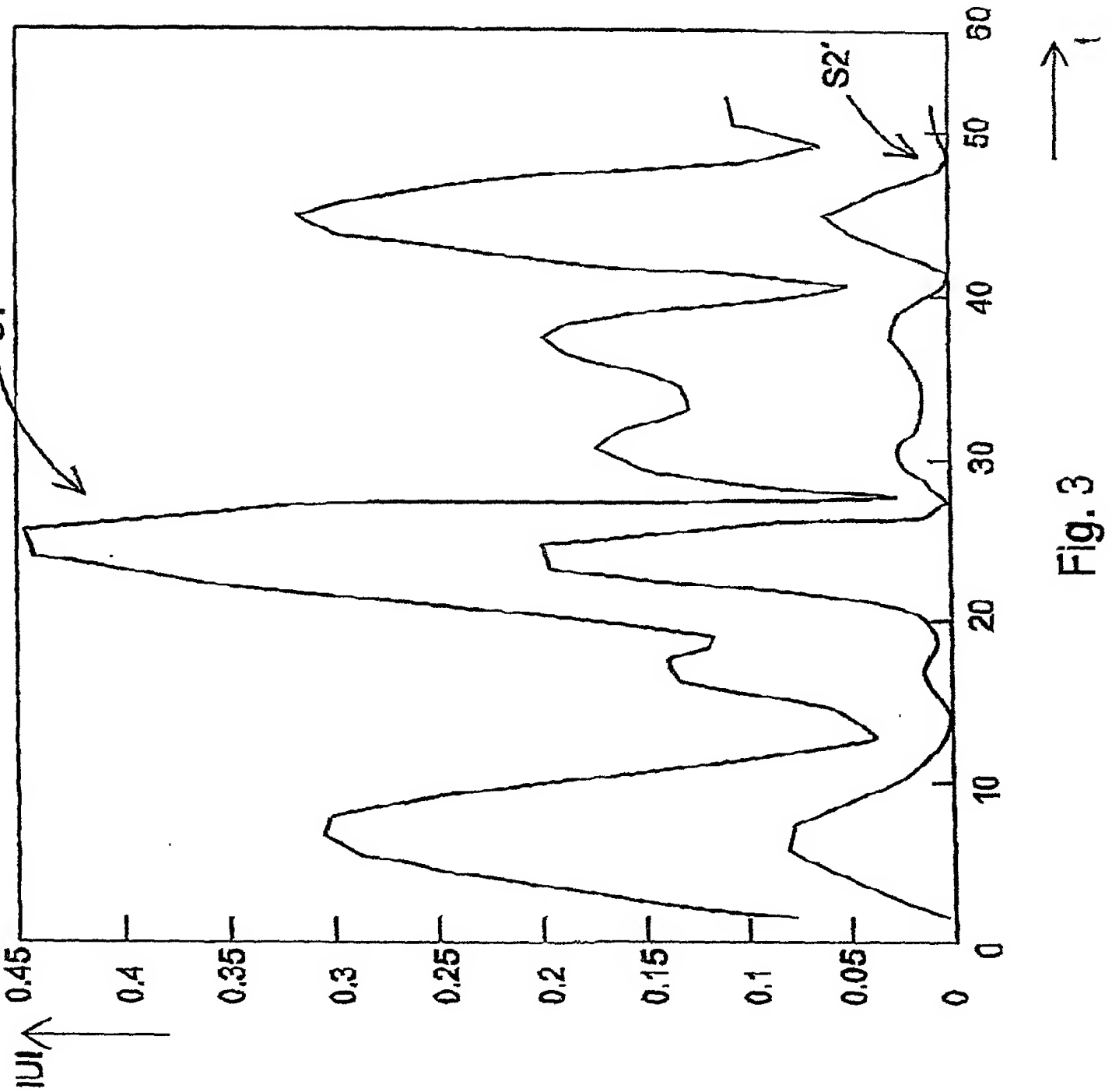


Fig. 3

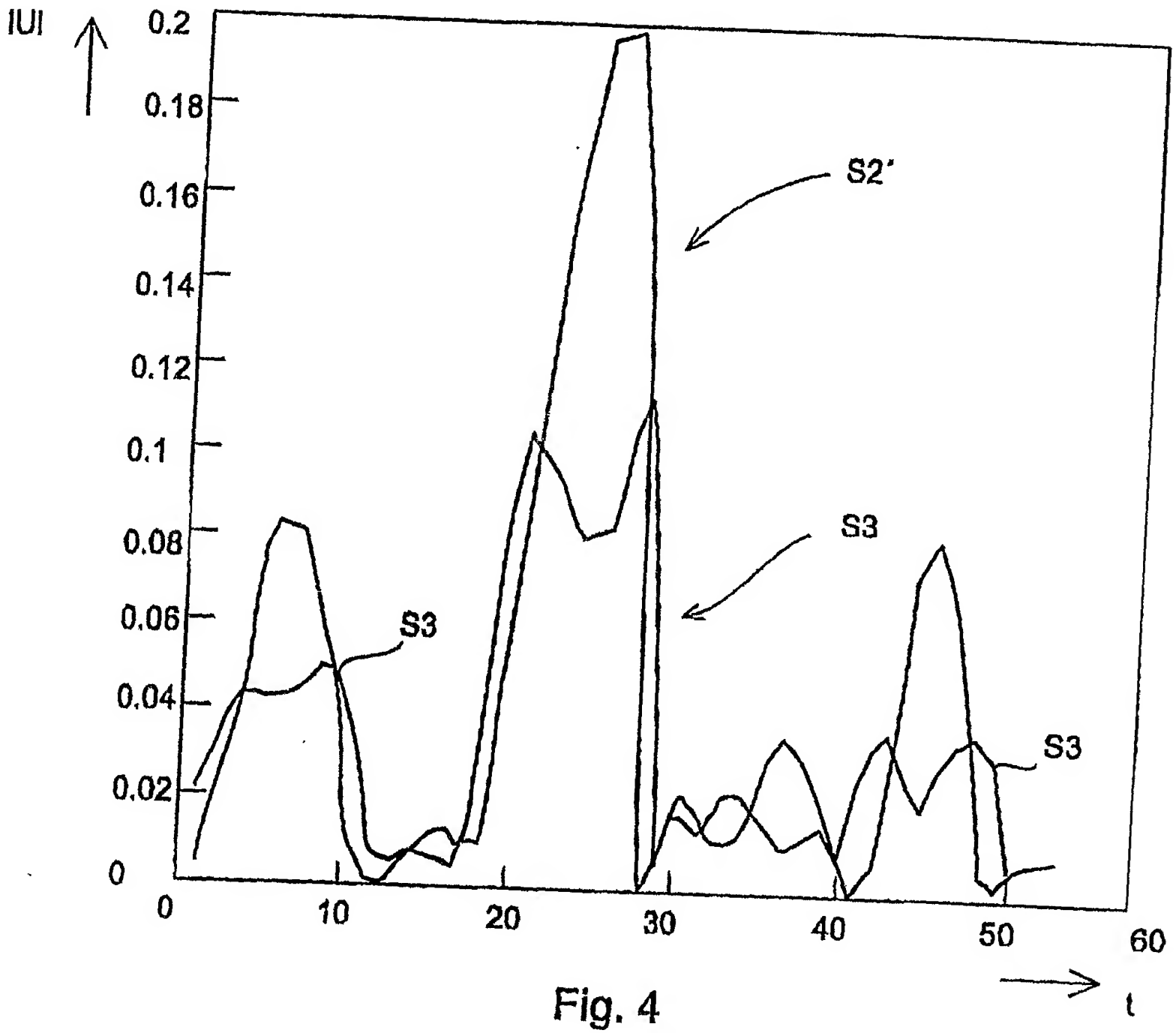
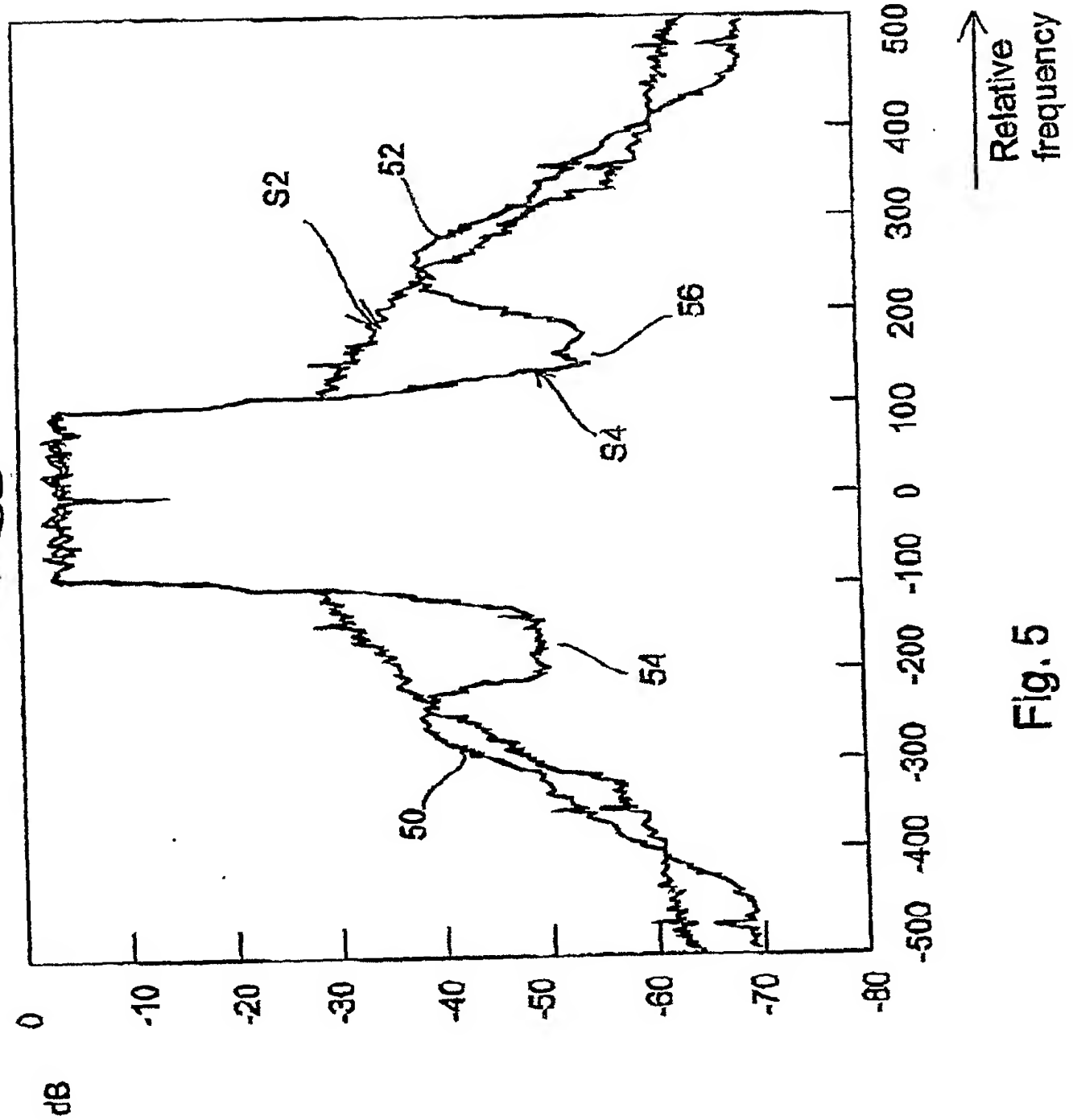


Fig. 4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S2
52
56
S4
50
54
dB
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-10
-20
-30
-40
-50
-60
-70
-80
500
400
300
200
100
0
-100
-200
-300
-400
-500
Relative frequency

Fig. 5

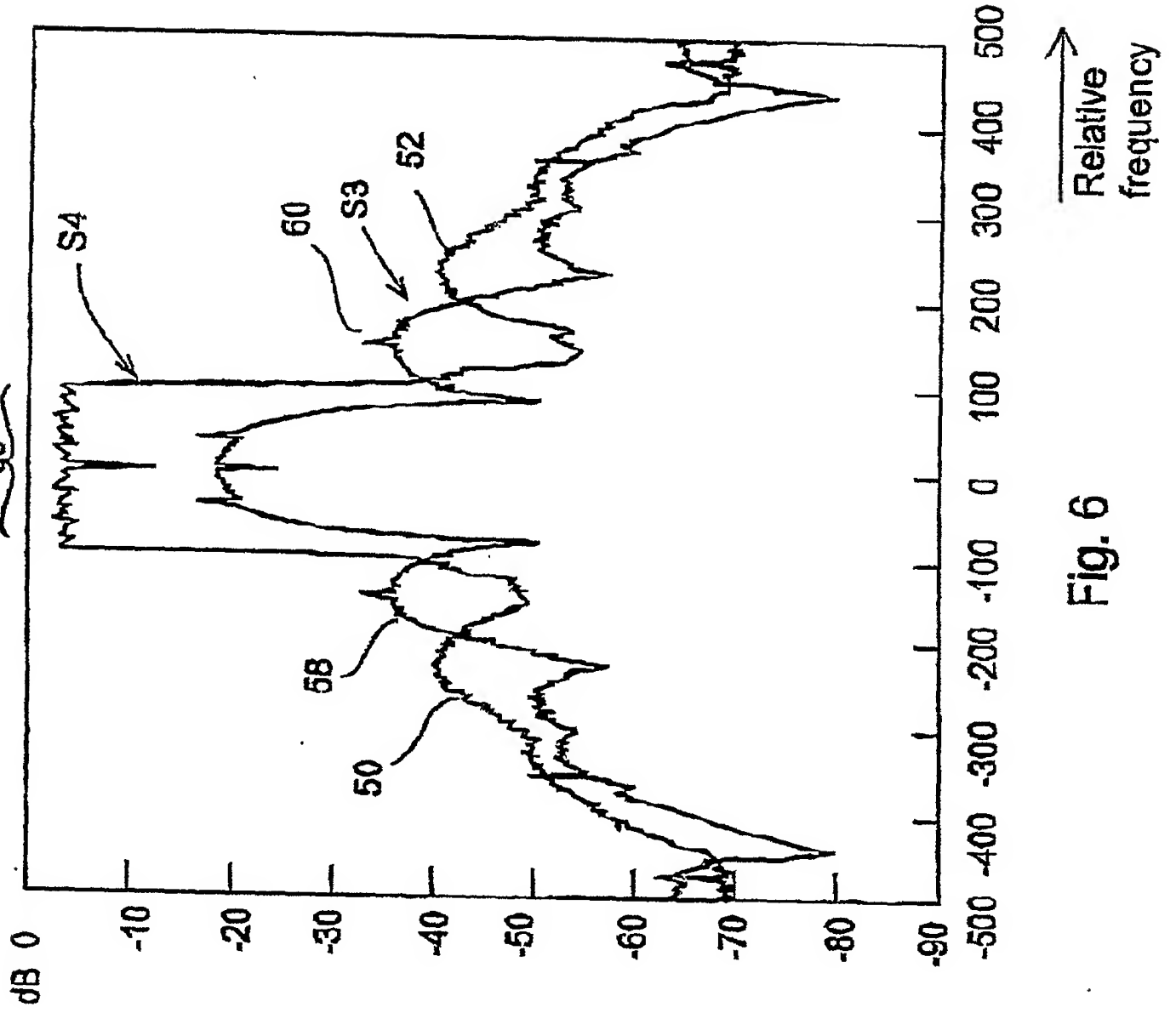

Fig. 6

#4

DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)

☐ Declaration Submitted with Initial Filing, OR
☒ Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16(e)) required)

Attorney Docket Number 33420.00.0001
First Named Inventor: Rainer Perthold
COMPLETE IF KNOWN
Application Number: 10/018,755
Filing Date: 12/17/01; I.A. Filing date: 05/19/2000
Group Art Unit:
Examiner Name:

As a below named inventor, I hereby declare that:
My residence, post office address, and citizenship are as stated below next to my name.
I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled: DEVICE AND METHOD FOR PREDISTORTING A TRANSMISSION SIGNAL TO BE TRANSMITTED VIA A NONLINEAR TRANSMISSION PATH

the specification of which:
☐ is attached hereto.
☒ was filed on 05/19/2000 as PCT International Application Number PCT/EP00/04580 and was amended on (MM/DD/YYYY)_____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.
I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Copy Attached? YES	NO
19927952.7	Germany	06/18/1999	☐	☐	☒
			☐	☐	☐

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Data (MM/DD/YYYY)

☐ Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto

I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application or PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number (if applicable)

☐ Additional U.S. or PCT international application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

As a named inventor, I hereby appoint the following registered practitioner(s) to prosecute this application and to transaction all business in the Patent and Trademark Office connected therewith:

Name	Registration Number	Name	Registration Number
Christopher J. Reckamp	34,414	Angelo J. Bufalino	29,622
Joseph P. Krause	32,578	Michael Turgeon	39,404
Christopher Moreno	38,566	Timothy J. Bechen	48,126

☐ Additional registered practitioner(s) named on supplemental Registered Practitioner Information sheet PTO/SB/02C attached hereto.\

Direct all correspondence to:

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor: ☐ A petition has been filed for this unsigned inventor

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Name of Additional Joint Inventor: ☐ A petition has been filed for this unsigned inventor

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Name of Additional Joint Inventor: ☐ A petition has been filed for this unsigned inventor

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Post Office Address			
City: Waischenfeld	State: Germany	ZIP: D-91344	Country: Germany

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☐ Additional inventors are being named on the ____ supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto.

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